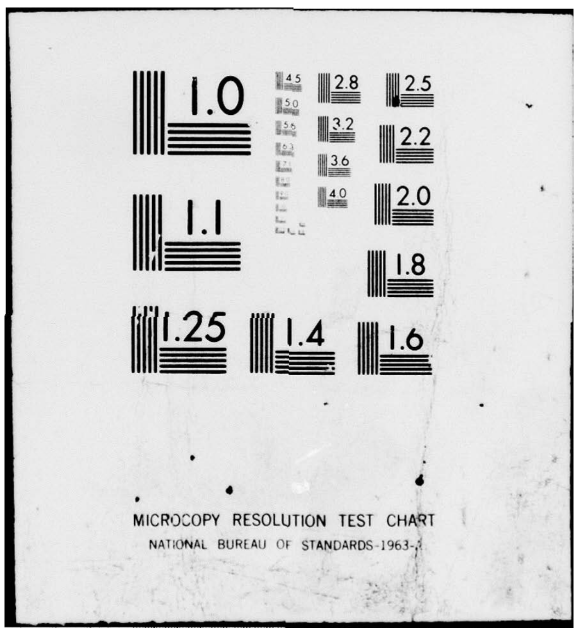
AD-A080 541 ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND ABERD--ETC F/G 19/1
RATE OF PENETRATION MEASUREMENTS.(U)
DEC 79 P H NETHERWOOD
UNCLASSIFIED ARBRL-MR-02978 SBIE-AD-E430 365 NL

1 OF 1
AD
A080541

END
DATE
FILMED
3-80
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(12) LEVEL III

AD-E430 365

AD

MEMORANDUM REPORT ARBRL-MR-02978

RATE OF PENETRATION MEASUREMENTS

Paul H. Netherwood, Jr.

December 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

14

1. REPORT NUMBER: MEMORANDUM REPORT ARBRL-MR-02978

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): 6 Rate of Penetration Measurements.

5. TYPE OF REPORT & PERIOD COVERED: 9 Final Neptis

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): 10 Paul H. Netherwood, Jr

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
USA Ballistic Research Laboratory
Aberdeen Proving Ground, MD 21005

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: RDT&E 1L161102AH43 16

11. CONTROLLING OFFICE NAME AND ADDRESS:
USA Armament Research and Development Command
Ballistic Research Laboratory
ATTN: DRDAR-BL
Aberdeen Proving Ground, Maryland 21005

12. REPORT DATE: 11 DEC[redacted]79

13. NUMBER OF PAGES: 27

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 26

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report):
Approved for Public Release; distribution unlimited.

18 SBIE

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
19 AD-E430 365

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
Ballistics, Long-Rod Penetrators, Penetration Velocity, Rolled Homogeneous Armor

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) bet, Ext. 2972

Records of the motion of the penetrator target interface have been obtained for impacts of steel long-rod penetrators against rolled homogeneous armor targets. Insulated wires inserted in drilled holes in the targets are used as switches which close when the penetrator contacts the wire. The results show a high penetration velocity immediately after impact, a rapid decrease to a nearly constant velocity, then an apparent velocity increase when the rear surface of the target fractures.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED 393 477

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

Page

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

Ballistic impacts occur over a wide range of impact velocities and involve many combinations of materials. Analytical work has tended to concentrate on two aspects of the problem: the low velocity regime where penetrator and target may be described as rigid or plastic, and the hypervelocity regime where both penetrator and target materials behave hydrodynamically. Practical cases of ballistic penetration often fall in the intermediate region where both projectile and target are severely deformed and eroded, but where material strength effects play a significant part.

One intermediate velocity case has been used by the Solid Mechanics Branch of the Terminal Ballistics Laboratory for a coordinated group of experimental studies intended to provide information for a complete analytical description. The standard conditions for these tests are:

Projectile:	8.13mm diameter, 250mm length, S-7 tool steel, without molybdenum, VIMVAR processing, hardened to RC47.[1]
Target:	25.4mm thick, 102mm diameter, rolled homogeneous steel armor (RHA),[2-5] cut from 102mm thick plate, plate, parallel to the plane of the plate.
Impact Velocity:	1000 m/s, normal impact.

The experimental studies using this case are instrumented rod tests by G. Hauver[6], shock mapping tests by D. Pritchard, and the projectile erosion/penetration velocity tests reported here.

---

[1]R. F. Benck, R. E. Franz, *"Quasi-Static Stress-Strain Curves, S-7 Tool Steel", BRL Memorandum Report in Preparation, Ballistic Research Laboratory, Aberdeen Proving Ground, MD.*

[2]G. E. Hauver, *"The Alpha-Phase Hugoniot of Rolled Homogeneous Armor", BRL Memorandum Report No. 2651, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1976.* (AD #B012871L)

[3]G. E. Hauver, A. Melani, *"The Epsilon-Phase Hugoniot of Rolled Homogeneous Armor," BRL Memorandum Report ARBRL-MR-02909, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1979.* (AD #A069107)

[4]R. F. Benck, *"Quasi-Static Tensile Stress Strain Curves--II, Rolled Homogeneous Armor," BRL Memorandum Report No. 2703, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, November 1976.* (AD #B016015L)

[5]R. F. Benck, J. L. Robitaille, *"Tensile Stress-Strain Curves--III, Rolled Homogeneous Armor at a Strain Rate of 0.42 S^{-1}," BRL Memorandum Report No. 2760, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1977.* (AD #A041560)

[6]G. E. Hauver, *"Penetration With Instrumented Rods," International Journal of Engineering Science, Vol. 16, pp. 871-877, November 1978.*

The experiments for these programs have been carried out using a 100mm diameter light-gas gun. The light-gas gun provides excellent control of projectile velocity and impact geometry. It does however, require use of a massive sabot which cannot readily be stopped by stripper plates, and has a rudimentary recovery system, meant to catch the target and projectile safely, rather than gently. The target chamber and catch tank must be evacuated, which limits the recovery media which can be used.

The case of steel on steel impact presents several problems for erosion and penetration velocity measurements. It is a low contrast situation, where it is difficult to differentiate projectile material from target material. Since the penetration velocity is low compared to the sound velocity in the target, shock waves will precede the projectile, and may affect the target material or gages. A plastic deformation zone also precedes the penetrator and can influence measurements.

The experimental design must also recognize that any alterations to the monolithic target may greatly alter the target response to impact. A laminated target is weaker than a solid one of the same thickness, and the penetration mechanism for a thin target is different from that for a thick target. Nevertheless, some alterations must be made to the target if measurements are to be accomplished.

II. EXPERIMENTS

A. Impedance Matched Target.

One technique used to reduce the effects of an interface in an experiment is to match, as closely as possible, the shock impedances of the materials on both sides of the interface. This reduces shock reflections at the interface and maximizes energy transfer to succeeding target elements. The Hugoniot curves for iron and lead lie very close together, suggesting that a target consisting of a thin steel front plate backed up by a massive lead rear plate might behave similarly to an all steel target. If this proved to be true, such a target could be used to determine projectile erosion rates. The thickness of the steel front plate could be varied, changing the amount of projectile destroyed. The residual rods would then be trapped in the lead, for recovery and measurement. At an impact velocity of 1000 m/s, the lead will behave hydrodynamically, but it was not clear whether passage through the lead would further erode the residual steel rod. In addition, it was not possible to perform a reliable calculation of the amount of lead required to capture the rod. The target chamber of the light-gas gun could not accommodate a target longer than about 432mm. A concept test target was assembled (see Figure 1), consisting of a steel sleeve filled with lead, with an aluminum back-up block and a perforated steel cover plate which allowed the penetrator to strike the lead without penetrating any steel. When the test was fired, the target was severely damaged. The steel shell split, allowing the lead to expand radially. One of the recovered

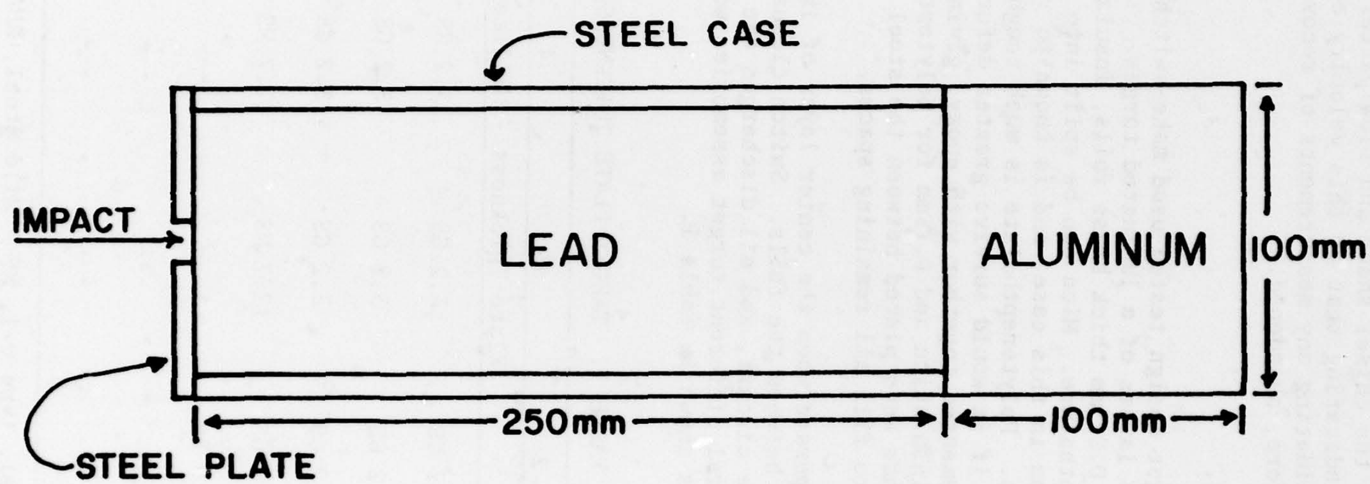


Figure 1. Schematic Diagram of Impedance Matched Target

rod fragments showed the chisel shape and flow pattern typical of an eroded penetrator, indicating that at this velocity contact with lead did erode the rod, invalidating any measurements of recovered rods. This approach was, therefore, abandoned.

B. Laminated Target.

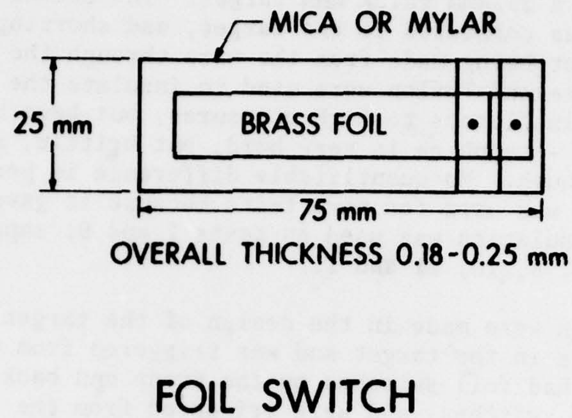
The second target design tested used make-switches (see Figure 2) inserted between the layers of a laminated target. The switches consisted of a pair of 0.025mm thick brass foils, insulated with thin sheets of mica or polyterepthalate. Mica can be split into very thin sheets, approximately 0.025mm in this case, and is known to remain insulating to high shock pressures. Polyterepthalate is much tougher than mica, and was tested to determine if it would survive greater deformation before failure. The switches were cemented together with epoxy, giving a total thickness of 0.15mm for mica insulation and 0.25mm for polyterepthalate insulation. The completed switches were placed between the steel layers of the target, and epoxy was used to fill all remaining spaces.

The switches operate when the center layer of insulation is broken and contact is made between the foils. Switch closure fires one unit of a multiple discharge circuit, and all discharges are recorded on an oscilloscope. Several different target assemblies were tested. A summary of target designs is shown in Table I.

TABLE I. TARGET PLATE THICKNESS

TEST NO. -	2	3	4	6
Plate No.	Plate Thickness - Millimetres			
1	3.2 GS	3.2 GS	3.2 GS	9.5 RHA
2	3.2 GS	3.2 GS	3.2 GS	3.2 RHA
3	3.2 GS	3.2 GS	3.2 GS	3.2 RHA
4	3.2 GS	12.7 MS	12.7 MS	3.2 RHA
5	7.9 BR	---	---	3.2 RHA
6	---	---	---	3.2 RHA
7	---	---	---	12.7 MS

GS = Tool Steel, Type 0-1, MS = Mild Steel, RHA = Rolled Homogeneous Steel Armor, BR = Brass



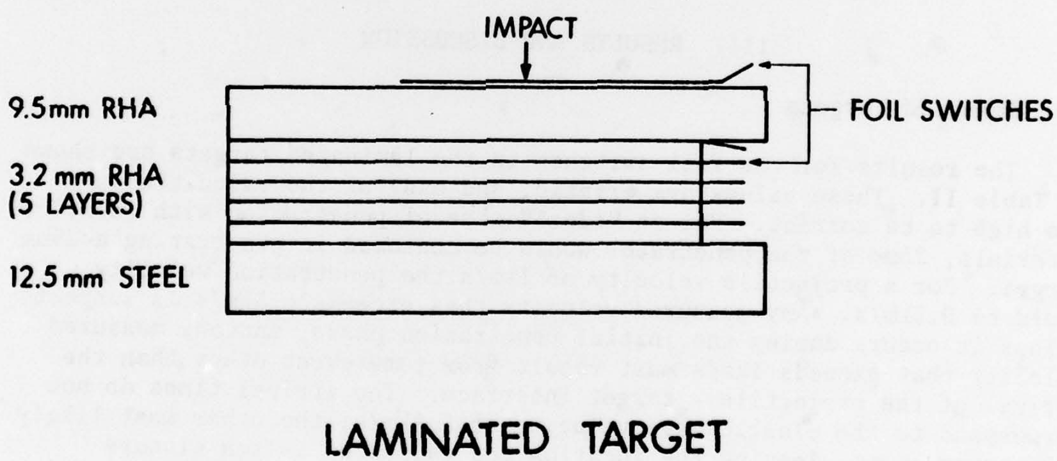


Figure 2. Schematic Diagram of Foil Switch and Laminated Target.

C. Drilled Target

The third target design (see Figure 3) used insulated wires placed in holes drilled in a 25.4mm thick RHA target. The second contact of the discharge circuit was connected to the target, and shorting of the switch depended upon contact being made from the wire through the projectile to the target. Sapphire and Teflon were used to insulate the wires. Both materials are good insulators to high pressures, but have very different mechanical behavior - sapphire is very hard, but brittle, and Teflon is very ductile, but tough. No quantifiable difference in performance was measured: Sapphire was used for more tests because it gave cleaner signals. Teflon insulation was used on tests 7 and 9; sapphire insulation was used on tests 5, 8, 10, 11 and 12.

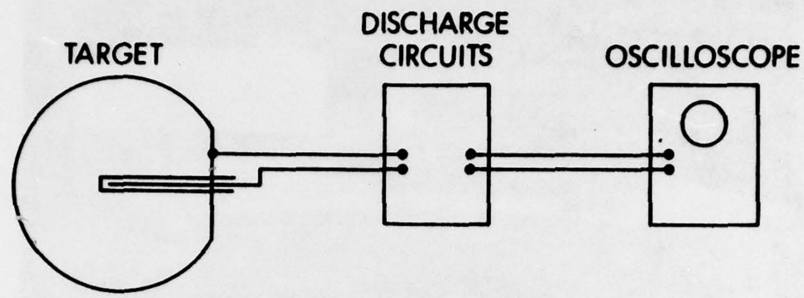
Several changes were made in the design of the targets. Test 5 used four insulated wires in the target and was triggered from wire #1. Tests 7, 8, 9, 11 and 12 had foil switches on the front and back of the targets, four insulated wire switches, and were triggered from the front foil switches. Test 10 had a foil switch on the front of the target, five insulated wire switches, and was triggered from the foil switch. An additional change was that the long-rod penetrators come from two manufacturers: Rods from batch 1 were used for tests 2 through 7; rods from batch 2 were used for tests 8 through 12.

III. RESULTS AND DISCUSSION

A. Laminated Targets

The results for the foil switches in the laminated targets are shown in Table II. These values are erratic, and many of the velocities are too high to be correct. For an "ideal" case of penetration with identical materials, 25mm of the penetrator would be consumed in penetrating a 25mm target. For a projectile velocity of 1km/s the penetration velocity would be 0.5km/s. Any measured velocity that exceeds 0.5km/s is suspect, unless it occurs during the initial penetration phase, and any measured velocity that exceeds 1km/s must result from some event other than the arrival of the projectile - target interface. The arrival times do not correspond to the elastic wave velocity of 5.8km/s, the other most likely triggering event, leaving the location and causes of switch closure unknown.

A second reason to distrust the laminated target results is discovered when the recovered targets are examined. For example, the through hole in target 6 was approximately 8mm in diameter, the size of the projectile, while the through holes in the solid targets were about 15mm. Much more metal was removed from the solid targets. The target material around the penetrator hole has been stretched and distorted much more in the laminated targets, as seen in Figures 4 and 5. Target 6 had a total thickness of 37.5mm and was penetrated, while a target of the same total



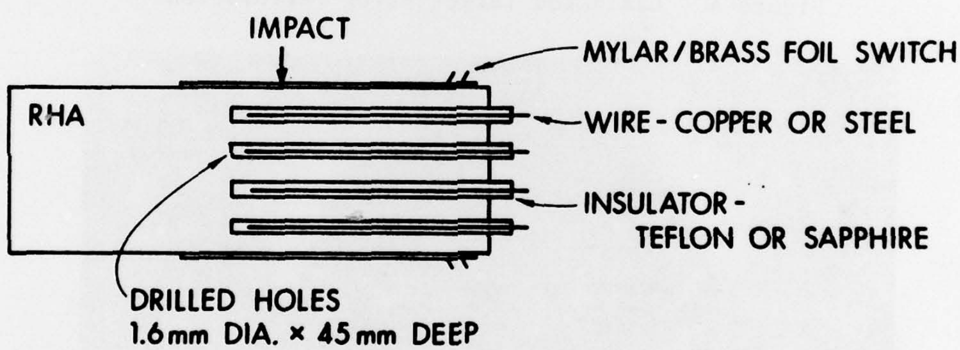


Figure 3. Schematic Diagram of Drilled Target Used For Tests 7, 8, 9, 11, 12

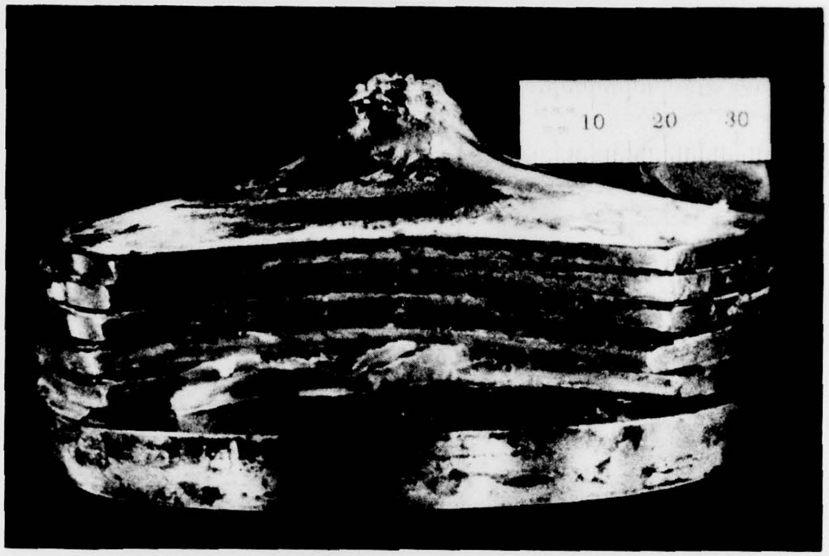


Figure 4. Laminated Target After Perforation.

Figure 5. Exit Hole in Drilled Target.

thickness but made up of only two layers of RHA, 12.7mm and 25.4mm thick, has defeated an identical projectile at this velocity[7]. The laminated target behaves as an array of thin plates which are perforated by the projectile, instead of reproducing the penetration behavior of the monolithic target.

TABLE II. PENETRATION VELOCITIES MEASURED FOR LAMINATED TARGETS

Test No.	2	3	4	6
Plate No.	Penetration Velocity - km/s			
1	2.5	0.1	2.3	0.5
2	2.0	1.0	2.4	0.3
3	1.1	0.7	0.8	0.7

B. Drilled Targets.

Previous experimental and theoretical studies of penetration in the hydrodynamic regime[8,9] have shown a consistent pattern: an entrance phase where penetration velocity is high, an intermediate phase where the velocity falls to a minimum, and an exit phase where the penetration velocity increases. Penetration velocity represents the rate of motion of the interface between the projectile and the target: it may also be regarded as the net velocity of the front end of the projectile as material is removed by erosion. For the case studied here, a high length to diameter ratio projectile which over-matches the target, the velocity of the back end of the rod remains nearly constant, while the erosion rate of the front end of the rod changes with time and location in the target. During the entrance and intermediate phases of penetration the erosion rate is high, and the penetration velocity is much lower than the projectile striking velocity. When the target plugs or fractures during the exit phase of penetration, the erosion rate decreases rapidly to zero, and the net velocity of the front end of the rod increases, returning to the velocity that the projectile as a whole has maintained during penetration.

---

[7]*D. S. Pritchard. Private communication, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, October 1978.*

[8]*J. R. Baker, "Rod Lethality Studies" NRL Report 6920, Naval Research Laboratory, Washington, D.C., July 1969.*

[9]*G. Weihrauch, "The Behavior of Copper Pins Upon Impacting Various Materials with Velocities Between 50 m/s and 1650 m/s", ISL Report 7/71, Franco-German' Research Institute, Saint-Louis, France, March 1971.*

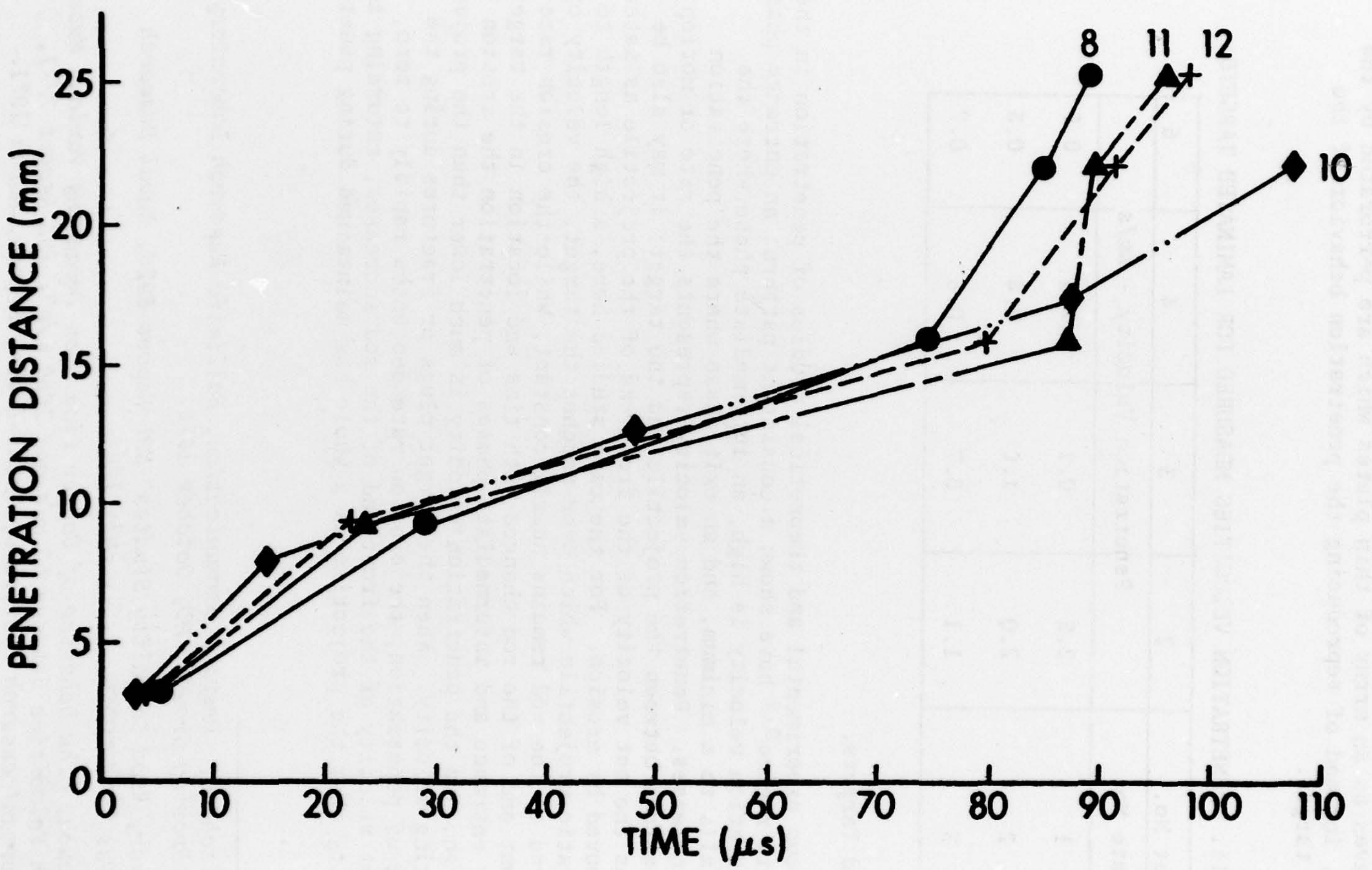


Figure 6. Penetration Curves For Long-Rod Impacts

TABLE III. TIME VS DISTANCE DATA FOR TESTS 5, 7, 8, 9, 11 AND 12

Test	#5	#7	#8	#9	#11	#12
ΔX - mm		ΔTime - Microseconds				
3.2 mm	--	3.7	5.4	5.2	4.1	4.1
6.4mm	24.8	17.8	23.6	17.8	19.5	18.4
6.4mm	74.2	76.9	45.5	52.3	63.6	57.2
6.4mm	--	5.9	10.7	13.1	2.4	11.7
3.2mm	--	12.7	3.8	4.4	6.4	6.7

TABLE IV. PENETRATION VELOCITY DATA FOR TESTS 5, 7, 8, 9, 11 AND 12

Test -	#5	#7	#8	#9	#11	#12
ΔX	Penetration Velocity - km/s					
3.18mm	0.83	0.59	0.61	0.77	0.78	
6.35mm	0.25	0.37	0.27	0.36	0.33	0.34
6.35mm	0.08	0.08	0.14	0.12	0.10	0.11
6.35mm	1.07	0.60	0.49	2.61	0.55	
3.18mm	0.25	0.85	0.70	0.49	0.47	

TABLE V. TIME, DISTANCE AND PENETRATION VELOCITY DATA FOR TEST NUMBER 10.

Location	ΔX mm	ΔT μs	V km/s
1 3.2mm	3.2	4.2	0.76
2 7.9mm	4.7	10.3	0.46
3 12.7mm	4.8	33.2	0.14
4 17.5mm	4.8	39.8	0.12
5 22.3mm	4.8	19.9	0.24

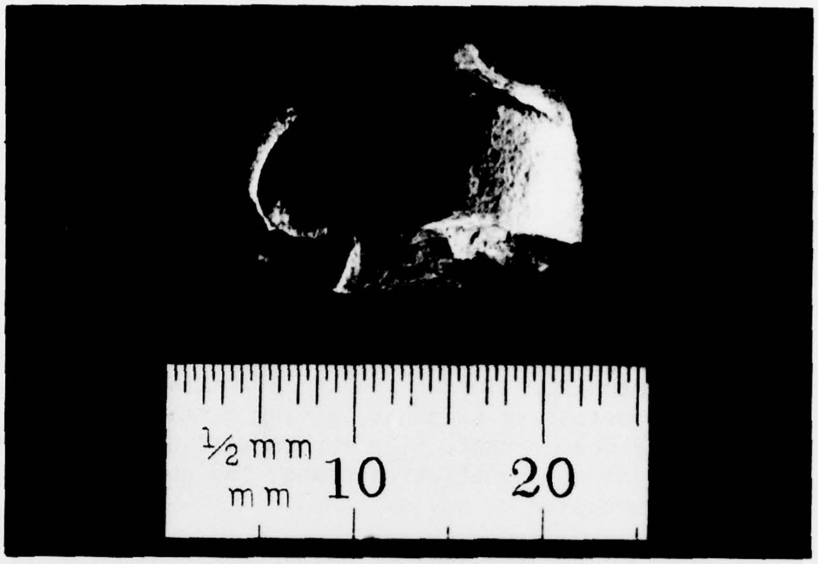
The results obtained from the insulated wire switch tests are shown in Tables III, IV, and V and Figure 6. They follow the expected pattern for the entrance and intermediate phases, but become inconsistent during the exit phase.

Inspection of the recovered targets shows that the drill holes influence the behavior of the target during the exit phase. The exit holes are not circular; they are roughly symmetrical about the line of the drill hole. The last few millimetres of the target material is either forced to the side as an exit crater lip, or separates as a semicircular piece of metal resembling half a plug. Several targets have the metal formed into a lip on one side and removed on the other side: Several have the metal removed on both sides. The separation process does not appear to be plugging in the accepted sense of the term: i.e., a disk which has been sheared out and pushed ahead of the projectile. The target material ahead of the penetrator splits along the plane of the drill holes, then either deforms or separates when pushed aside by the penetrator. One-half plug has been recovered (see Figure 7), which weighs 8 grams, and shows a groove along the straight edge corresponding to the final drill hole. This fragment shows that the projectile did not touch the final drilled hole switch. The velocities calculated for the later switch closures are erratic, and include values which exceed the impact velocity. These measurements are clearly influenced by the rear-surface events, and cannot be accepted as representing the actual interface motion. The measurement technique works correctly during the entry and steady-state stages of penetration, then fails when the target splits or plugs.

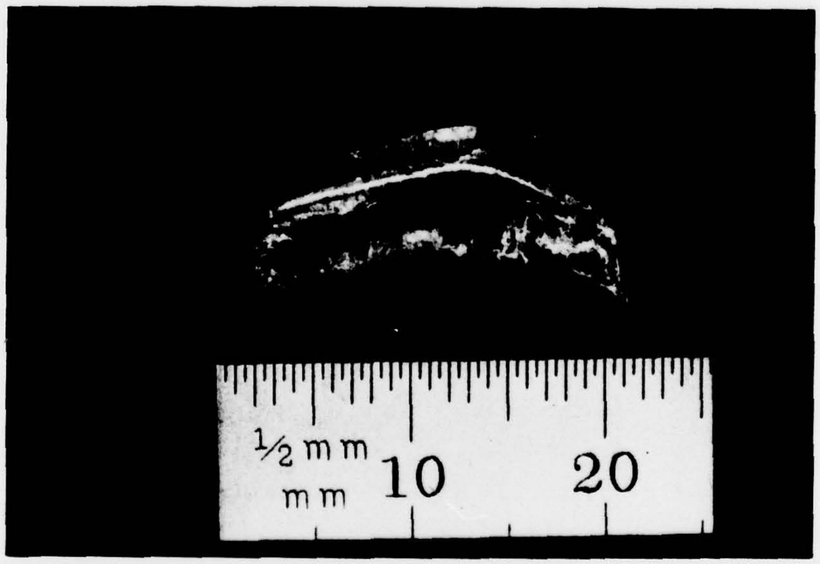
The residual penetrators are usually broken up during the stopping process in the catch tank, but several rods showing the chisel nose and flow marks typical of an eroded penetrator have been recovered in one piece. They are badly deformed, so that length measurments are unreliable, but the amount eroded can be calculated from the mass loss. The measurements for these rods are given in Table VI. Since the recovery process is not carefully controlled, these values can be taken only as an upper limit for the material eroded during penetration.

TABLE VI: RESIDUAL PENETRATORS

Test No.	Weight, Initial gm	Weight, Recovered gm	Length Eroded mm
8	101.8	67.4	86
11	101.9	64.3	94
12	101.9	69.8	80



Top View



Side View

Figure 7. Top View and Side View of Half-Plug Ejected From Rear Surface of Drilled Target.

The penetration velocities have been calculated based upon the assumption that shorting occurs when the projectile erodes away the insulation and touches the wire. It is possible that shorting occurs, prior to the actual arrival of the projectile, as a result of the mechanical deformation zone which precedes the projectile-target interface. If premature shorting of the switches does occur, the consequences will depend upon the magnitude and reproducibility of the time difference between shorting and the actual arrival of the interface. Weihrauch[9], and Lehr and Weihrauch[10], have shown that the front of the deformation zone moves faster than the interface during the initial stages of penetration. After a sufficient depth of penetration, a steady-state condition is set up, and the front of the deformation zone stabilizes at a fixed distance ahead of the interface. In each experiment, the switches are identical in construction, therefore they should short after similar amounts of deformation. The time errors during the steady-state period should then be the same for two successive switches, giving a nearly correct time interval and velocity measurement. The errors will change with switch location during the initial penetration phase, and absolute times of arrival will not be measured by any switches.

Additional assumptions implicit in the penetration velocity calculations are that the target is stationary, and that it does not change shape. Both of these assumptions are known to be incorrect. The deformation zone ahead of the interface will result in bulging of the target. The location of the switch at the time of contact, therefore, may be displaced from the measured location prior to impact. As in the case of premature switch closure, this error should be nearly constant for switches located in the steady-state zone, minimizing the effect on Δtime measurements, but will change with switch location during the initial penetration phase.

Momentum transferred to the target from the projectile will set the target in motion down range. This movement will result in Δtime measurements exceeding the times actually needed for the measured amount of penetration. The magnitudes of the errors from this cause are best determined by direct measurement of target motion, and future tests will measure penetration velocity and target motion simultaneously.

IV. CONCLUSIONS

Location vs time histories have been obtained for steel long-rod penetrators impacting rolled homogeneous armor targets. The results show that penetration velocity is high immediately after impact, then falls to a nearly constant value. The measurement technique fails when the rear surface of the target splits or plugs. The results are reproducible and indicate that the use of embedded switches is a valid technique for measuring penetration.

---

[10] *H. F. Lehr, G. Weihrauch, "Target Deformation in Front of a Hydrodynamically Penetrating Rod Projectile. Analysis of Experiments," Technical Report RT 14/73, German-French Research Institute, Saint-Louis, West Germany, October 1973.*

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of Donovan Thurn and Michael Blount, who make the Light-Gas Gun function.

41

REFERENCES

1. R. F. Benck, R. E. Franz, "Quasi-Static Stress-Strain Curves, S-7 Tool Steel, BRL Memorandum Report in Preparation, Ballistic Research Laboratory, Aberdeen Proving Ground, MD.

2. G. E. Hauver, "The Alpha-Phase Hugoniot of Rolled Homogeneous Armor," BRL Memorandum Report No. 2651, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1976. (AD #B012871L)

3. G. E. Hauver, A. Melani, "The Epsilon-Phase Hugoniot of Rolled Homogeneous Armor," BRL Memorandum Report ARBRL-MR-02909, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1979. (AD #A069107)

4. R. F. Benck, "Quasi-Static Tensile Stress-Strain Curves--II, Rolled Homogeneous Armor," BRL Memorandum Report No. 2703, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, November 1976. (AD #B016015L)

5. R. F. Benck, J. L. Robitaille, "Tensile Stress-Strain Curves--III, Rolled Homogeneous Armor at a Strain Rate of 0.42 S^{-1}, BRL Memorandum Report No. 2760, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1977. (AD #A041560)

6. G. E. Hauver, "Penetration With Instrumented Rods," International Journal of Engineering Science, Vol. 16, pp. 871-877, November 1978.

7. D. Pritchard. Private communication, Ballistics Research Laboratory, Aberdeen Proving Ground, MD, October 1978.

8. J. R. Baker, "Rod Lethality Studies" NRL Report 6920, Naval Research Laboratory, Washington, D.C., July 1969.

9. G. Weihrauch, "The Behavior of Copper Pins Upon Impacting Various Materials with Velocities Between 50 m/s and 1650 m/s," ISL Report 7/71, Franco-German Research Institute, Saint-Louis, France, March 1971.

10. H. F. Lehr, G. Weihrauch, "Target Deformation in Front of a Hydrodynamically Penetrating Rod Projectile. Analysis of Experiments," Technical Report RT 14/73, German-French Research Institute, Saint-Louis, West Germany, October 1973.

DISTRIBUTION LIST

No. of Copies	Organization	No. of Copies	Organization
12	Commander Defense Technical Info Center ATTN: DDC-DDA Cameron Station Alexandria, VA 22314	1	Commander US Army Aviation Research and Development Command ATTN: DRSAV-E P.O. Box 209 St. Louis, MO 63166
1	Director Defense Advanced Research Projects Agency ATTN: Tech Info 1400 Wilson Boulevard Arlington, VA 22209	1	Director US Army Air Mobility Research and Development Laboratory Ames Research Center Moffett Field, CA 94035
1	Deputy Assistant Secretary of the Army (R&D) Department of the Army Washington, DC 20310	1	Commander US Army Communications Rsch and Development Command ATTN: DRDCO-PPA-SA Fort Monmouth, NJ 07703
1	Commander US Army Materiel Development and Readiness Command ATTN: DRCDMD-ST 5001 Eisenhower Avenue Alexandria, VA 22333	3	Commander US Army Electronics Research and Development Command ATTN: DELSD-L DELEW-E DELET-IR Fort Monmouth, NJ 07703
2	Commander US Army Armament Research and Development Command ATTN: DRDAR-TSS (2 cys) Dover, NJ 07801	1	Commander US Army Harry Diamond Labs ATTN: DRXDO-TI 2800 Powder Mill Road Adelphi, MD 20783
1	Commander US Army Armament Materiel Readiness Command ATTN: DRSAR-LEP-L, Tech Lib Rock Island, IL 61299	2	Commander US Army Missile Research and Development Command ATTN: DRDMI-R DRDMI-YDL Redstone Arsenal, AL 35809
2	Commander US Army Watervliet Arsenal ATTN: Dr. F. Schneider DRDAR-LCB-TL Watervliet, NY 12189	2	Commander US Army Mobility Equipment Research & Development Cmd ATTN: DRDME-WC STSFB-MW, Dr. J. Bond Fort Belvoir, VA 22060

DISTRIBUTION LIST

No. of Copies	Organization
1	Commander US Army Tank Automotive Rsch and Development Command ATTN: DRDTA-UL Warren, MI 48090
1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL, Tech Lib White Sands Missile Range NM 88002
5	Commander US Army Materiel and Mechanics Research Center ATTN: DRXMR-ATL DRXMR-H, Mr. J. Dignam DRXMR-H, Dr. D. Dandekar DRXMR-T, Dr. J. Mescall DRXMR-H, Dr. S. C. Chou Watertown, MA 02172
1	Commander US Army Research Office P. O. Box 12211 Research Triangle Park NC 27709
1	Commander US Military Academy ATTN: Library West Point, NY 10996
1	Commander Naval Research Laboratory ATTN: Code 2020, Tech Lib Washington, DC 20375
3	Commander Naval Surface Weapons Center ATTN: Mr. W. H. Holt Mr. W. Mock, Mr. DX-21, Lib Dahlgren, VA 22448
2	Commander Naval Surface Weapons Center ATTN: Dr. J. W. Forbes Tech Lib Silver Spring, MD 20910
1	AFWL (Tech Lib) Kirtland AFB, NM 87117
1	Director Lawrence Livermore Laboratory ATTN: Dr. M. van Thiel, L-64 P. O. Box 808 Livermore, CA 94550
3	Sandia Laboratories ATTN: Tech Lib Dr. W. Herrmann Dr. L. D. Bertholf Albuquerque, NM 87115
3	SRI International ATTN: Dr. G. R. Abrahamson Dr. D. Curran Dr. L. Seaman 333 Ravenswood Avenue Menlo Park, CA 94025
1	Drexel Institute of Technology Wave Propagation Research Center ATTN: Prof. P. C. Chou 32nd and Chestnut Streets Philadelphia, PA 19104
2	University of California Los Alamos Scientific Lab. ATTN: Tech Lib GMX-6, Dr. J. W. Taylor P. O. Box 1663 Los Alamos, NM 87545
1	Washington State University Department of Physics ATTN: Prof. G. E. Duvall Pullman, WA 99163

DISTRIBUTION LIST

Aberdeen Proving Ground

Dir, USAMSAA
  ATTN: DRXSY-D
        DRXSY-MP, H. Cohen
Cdr, USATECOM
  ATTN: DRSTE-TO-F
Dir, Wpns Sys Concepts Team,
  Bldg. E3516, EA
  ATTN: DRDAR-ACW

USER EVALUATION OF REPORT

Please take a few minutes to answer the questions below; tear out this sheet and return it to Director, US Army Ballistic Research Laboratory, ARRADCOM, ATTN: DRDAR-TSB, Aberdeen Proving Ground, Maryland 21005. Your comments will provide us with information for improving future reports.

1. BRL Report Number ____________________

2. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

____

____

____

3. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.) ____________________

____

____

4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

____

____

5. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.) ____________________

____

____

____

6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: ____________________

Telephone Number: ____________________

Organization Address: ____________________

____

____